

The Raytheon DB-110 Sensor: Four Cameras in One Package

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ABSTRACT

Raytheon has designed, manufactured, and flight-tested a new reconnaissance system. The Raytheon DB-110 reconnaissance system is effectively four sensors in one, utilizing simultaneous visible and infrared focal plane assemblies with selectable long-range or short-range optics. This capability permits reconnaissance missions to be conducted from very short range to long range by day or night. This paper reviews the design objectives, system characteristics and example flight test imagery from the Raytheon DB-110 system.

1. INTRODUCTION

Optical reconnaissance sensors are undergoing a revolution from primarily daytime-only film camera based systems to 24-hour, day/night digital sensor systems. The changing world environment, in terms of technological advances and new operational requirements, has brought about this transition. There is a worldwide trend to replace film LOROP (LONG-Range Oblique Photographic) cameras with dual-band E-O/IR (electro-optical/infrared) systems.

Raytheon Systems Company has developed a dual-band reconnaissance sensor, designated the DB-110, to meet the requirements of both close-range tactical and LOROP reconnaissance missions. The system is unique in that two optical systems are incorporated into a single system. This gives a mission planner the ability to optimize collections for sorties that previously required different sensors, or possibly even different platforms, to accomplish.

This paper reviews the traditional categories of reconnaissance sensors as background to the DB-110 development objectives in Section 2. The characteristics and operations of the DB-110 system are described in Section 3. Section 4 illustrates the multi-mission capabilities presented by the DB-110 within a matrix of standard reconnaissance mission types. Finally, Section 5 presents examples of DB-110 flight test imagery which demonstrate the performance of the system under day and night collection conditions.

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2. BACKGROUND

2.1 Types of Airborne Reconnaissance Sensors

Airborne reconnaissance (recce) sensors are generally categorized by their mission type and altitude range as illustrated in Figure 1. Descriptions and examples of these categories follow.

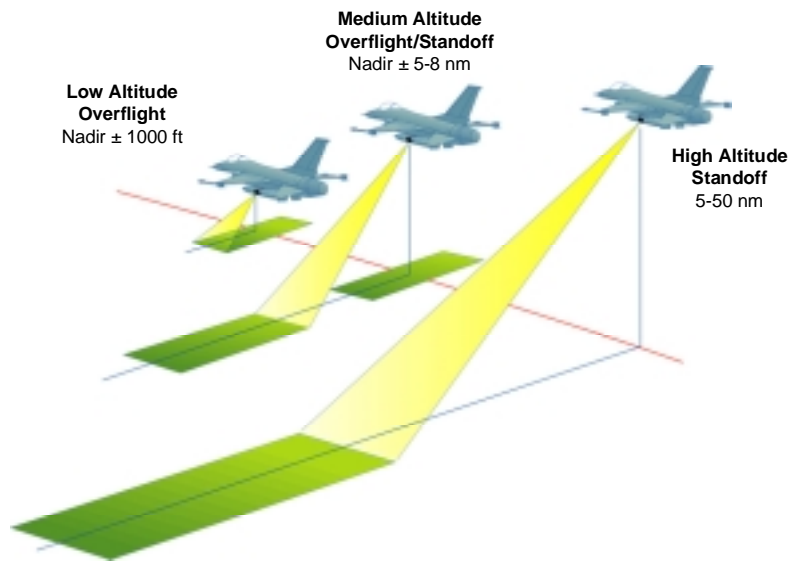


Figure 1. Traditional Recce Mission Categories

High speed, low-altitude penetrating missions are employed in high threat (wartime) environments to collect imagery directly over targets (nadir \pm 5,000 ft swath width). Altitude ranges of 200-3,000 ft are typical, as are high velocity/range (V/R) ratio operation. Due to the short range to target and high V/R, low altitude sensors are based on short focal length optical systems. The Low Altitude Electro-Optical (LAEO) sensor (1-inch focal length) used in the US Marine Corps ATARS (Advanced Tactical Air Reconnaissance System) used in the F-18 platform is one such example.

Medium altitude missions are used to collect imagery for both overflight and standoff missions. In general, medium altitude operations are in the range of 2,500-25,000 ft. In high threat environments, an aircraft would fly a low-altitude penetration mission, pop-up to medium altitude to quickly image the area of interest, and then revert to low-altitude for safe exit. In lower threat environments, the platform may fly at medium altitude and image at either nadir (overflight) or at left, right or forward oblique (standoff).

Medium altitude sensors employ focal lengths generally in the 6-18 inch range. In the ATARS sensor suite, the 12-inch focal length Medium Altitude Electro-Optical (MAEO) sensor is utilized for side looking oblique (pushbroom) imaging in the daytime. The Predator UAV (Unmanned Aerial Vehicle) utilizes day and night video sensors with zoom optics.

LOROP (Long-range Oblique Photographic) sensors systems are utilized to image at long-range in peacetime as well as in threat environments. The high altitude category is generally applied to systems typically operating in the 20,000-50,000 foot range (and above on special mission platforms). The fundamental design characteristic to support long-range operations is focal length. LOROP's employ focal lengths of 36-inches or greater.

LOROP collections are generally at standoff ranges starting from 5 to 10 miles out to the horizon. In the United States, the only operational LOROP system is the Raytheon SYERS (Senior Year Electro-Optical Sensor) operating on the U-2 aircraft. The Global Hawk UAV is also high-altitude standoff platform utilizing the Raytheon Integrated Sensor System (ISS). The ISS payload contains an optical sensor with a 70-inch focal length in both the visible and infrared (IR) spectrums, in addition to an integrated synthetic aperture radar system.

2.2 DB-110 Design Objectives

Raytheon conducted a survey of reconnaissance users in the early part of the 1990's to assess the potential for a new product in the marketplace. It was apparent that a change would occur worldwide with a transition from film-based reconnaissance to digital electro-optical sensors. Film systems could not support 24-hour reconnaissance, nor could they easily support the rapid timelines needed in the modern world from collection of information to delivery to the warfighter. Logistical and environmental considerations also favored the transition to an all-electronic system to eliminate the support for wet-film processing and disposal of chemistry.

In addition to the technological evolution from film to digital systems, the Raytheon survey also indicated a shift in mission requirements. During the Cold War, the predominant tactical recce mission anticipated was low-altitude overflight to operate in a wartime/high-threat environment. Following the Cold War, and with the experience of Desert Storm, military recce requirements underwent a change in emphasis. Most recce operations today and in the future will occur during peacetime. Overflying a neighboring country is unacceptable; a border surveillance mission must be flown in order to collect intelligence information. Long-range standoff (long focal length) systems are essential to collect useful imagery. Peacekeeping missions (Bosnia, Southern Watch) are usually restricted to a minimum altitude (e.g. 10,000 feet), therefore also mandating longer focal length sensors to achieve high quality imagery.

Still, recce capabilities must be available for crisis and wartime environments. Both low altitude overflight and medium altitude (pop-up) systems will be used in high threat environments, as will high altitude standoff sensors which increase survivability by collecting imagery far from ground-based threats. Flexibility to reprogram missions is an implicit requirement in order to adjust collection strategies in a dynamic environment, for example to collect Targets of Opportunity.

Raytheon designed a new sensor, designated as the DB-110 (dual-band 110-inch focal length), to be responsive and flexible with respect to changing world requirements. Basic design objectives were to accomplish the following:

- Achieve high performance in both day and night missions
- Support both close range and mid/long standoff range missions in a single sensor
- Minimize size and weight to permit carriage onboard multiple platforms
- Design a stabilization system for high dynamics of tactical aircraft
- Minimize cost by use of COTS equipment where possible
- Produce a modular design to facilitate tailoring to individual customer requirements

3. DB-110 SYSTEM CHARACTERISTICS

3.1 DB-110 Development

Even more important than the design objectives cited in Section 2.2 was to have a proven capability. Both domestic and international customers were skeptical of a “paper design.” An in-flight performance demonstration was considered essential to prove design objectives were met.

In response to a “Fly Before Buy” imperative, Raytheon designed, built and flew the DB-110 sensor in the 1995-1997 time period. Raytheon selected the UK for their 1997 demonstration as the MOD was conducting a competition for the Royal Air Force (RAF) Tornado aircraft reconnaissance upgrade. This program, Reconnaissance Airborne Pod (RAPTOR), was awarded to Raytheon, and is described later in this paper.

3.2 System Description

The fundamental design characteristic of the Raytheon DB-110 was to be able to image at day and night. This objective was translated into operation by the use of a common telescope with two sets of focal planes – visible and mid-wave infrared. Figure 2 illustrates this design. A long range telescope, shown pointing to nadir, collects energy of the ground scene. The long-range telescope provides focal lengths of 110-inches and 55-inches in the EO and IR, respectively. A beam-splitter behind that telescope separates the visible and infrared wavelength energy. Independent relay optics focus this energy onto separate visible and infrared focal planes.

The short-range optics are located on the opposite side of the long range telescope and consist of a 16-inch focal length EO and a 14-inch IR system. Each of these separate optics use the same focal planes as does the long-range system. In operation, either the long- or short-range system can be used. The roll gimbal rotates the DB-110 system 180° to point the desired optic through the aircraft window.

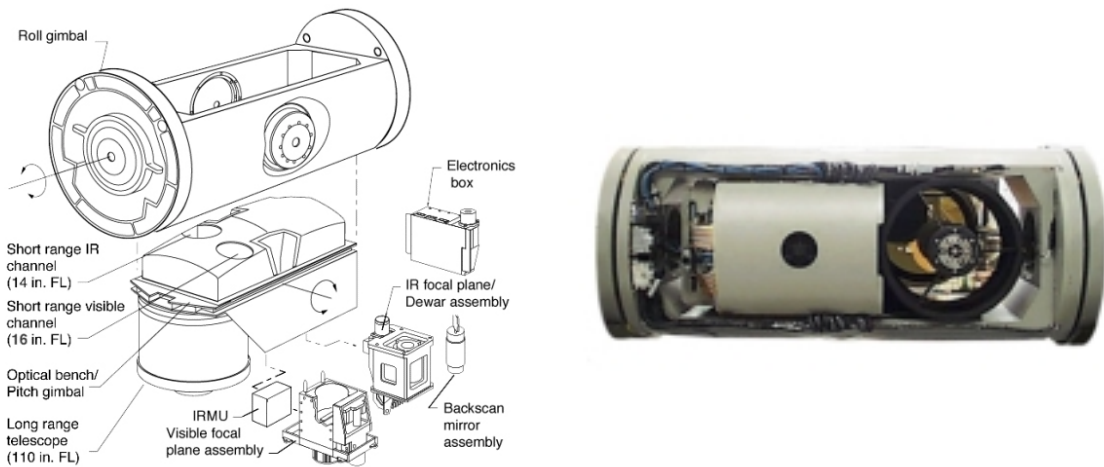


Figure 2. Schematic illustration of DB-110 design (left) and hardware photograph (right).

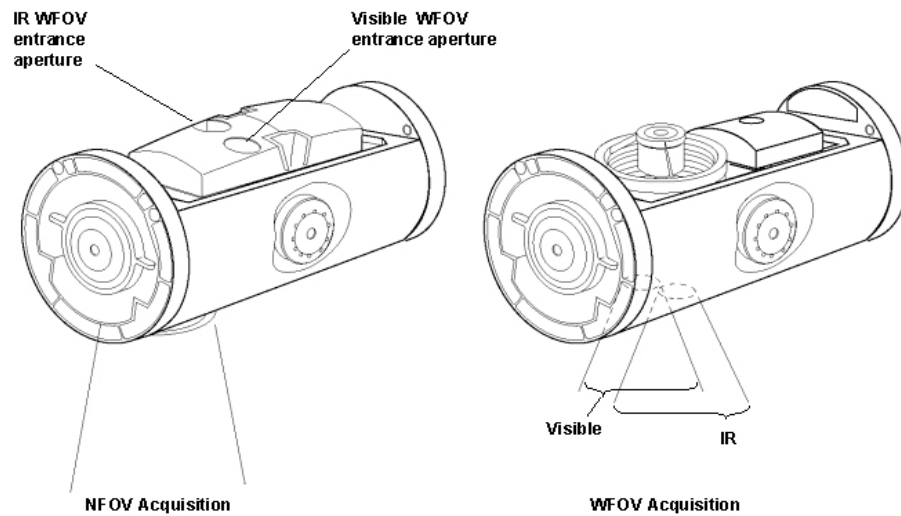


Figure 3. Notional illustration of pointing operations using the long-range (narrow field of view) system (left) and short-range (wide field of view) optics (right).

Table 1 lists the physical parameters of the DB-110 system.

Table 1. DB-110 System Parameters

Sensor Characteristics	Visible	Common	Mid-Wave Infrared
	<i>Long Focal Length Optics</i>		
Focal length (inches)	110		55
Relative aperture	f/10		f/5

Sensor Characteristics	Visible	Common	Mid-Wave Infrared
	<i>Wide Field of View/Short Focal Length Optics</i>		
Focal length (inches)	16		14
Relative aperture	f/10		f/5
Operating mode		Pan scan	
Overlap		Selectable (0 to 100%)	
Cross-track field of regard		180°	
Along-track field of regard		±20°	
Focal plane type	Silicon CCD (5,120 x 64 stages TDI)		Indium Antimonide (2 FPA, each 512 x 484)
Quantization	10 bit		12 bit
Spectral range	0.4 to 1.0 μm		3.0 to 5.0 μm
Image stabilization		2 axis roll and pitch	Backscan mirror
Size (inches)		50 long x 18.5 diameter	

3.3 DB-110 Collection Operations

The DB-110 operates as a pan-scanning system, in that it scans the ground scene perpendicular to the flight path, as illustrated in Figure 4. It has horizon to horizon (180°) field of regard. A roll gimbal provides the scanning motion, and a pitch gimbal controls the forward motion compensation (FMC). To maximize scan efficiency, the system utilizes a bi-directional imaging capability, i.e., imagery is collected both while scanning out toward the horizon from the aircraft track and back.

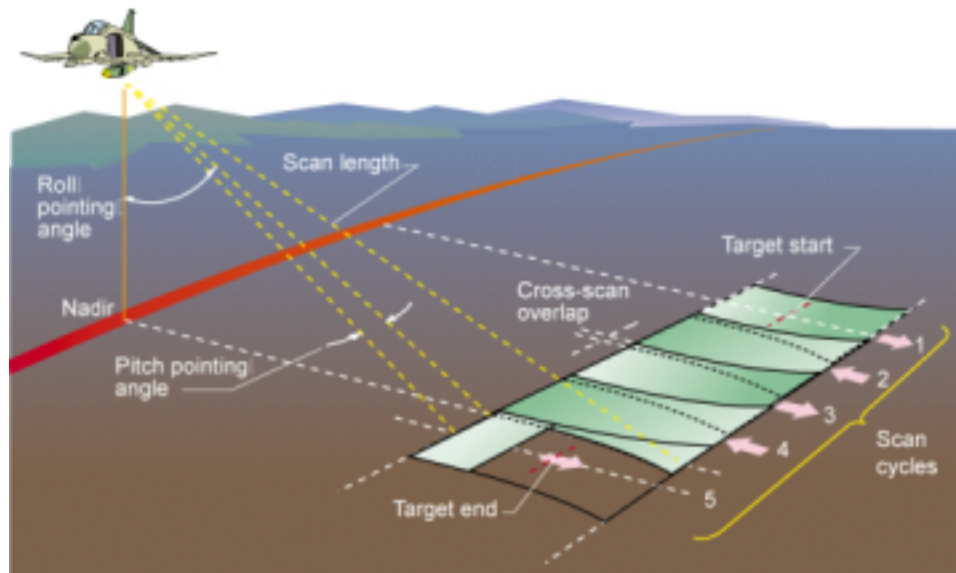


Figure 4. DB-110 Pan Scan collection geometry.

The visible waveband channel uses a line array to form continuous scans, while the IR channel uses two area arrays. This is illustrated in Figure 5 where the upper rectangles indicate the operation of the area arrays. Individual IR frames are collected in what is called a “step-stare” method. The area arrays are focused (held constant) on a single ground area for the duration of an exposure. A backscan mirror is used to keep the line-of-sight stationary during the integration period. Once the exposure is completed, the arrays are projected to the next ground position, overlapping the first exposure by a small amount to maintain contiguous coverage. When the image is reconstructed on the ground, both images will appear to be a continuous scan to the viewer.

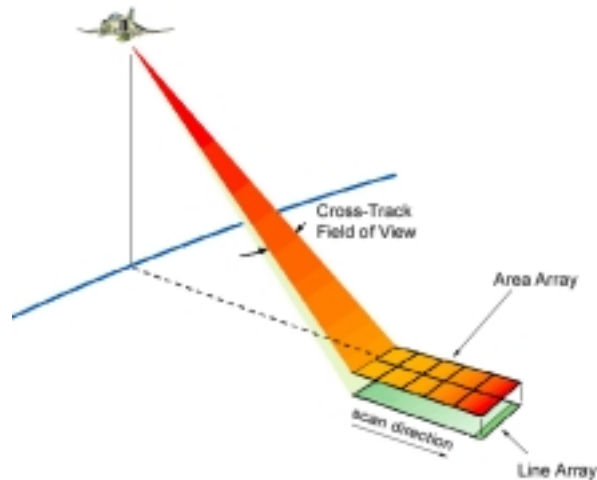


Figure 5. DB-110 uses a line array and area array simultaneous to acquire dual-band imagery.

The sensor has three main collection modes: (1) wide area search, (2) spot, and (3) stereo/target tracking. For the wide area search mode the scan length is calculated based on the velocity over slant range (V/R), and provides contiguous imagery for as long as required. In spot and stereo/target tracking mode, the sensor can pitch $\pm 20^\circ$, shown in Figure 6. When using the spot mode, first the scan length is defined for the required coverage and then the V/R and available pitch travel are calculated to determine the number of contiguous scans that can be collected. Stereo/target tracking mode is similar to spot, but is limited to approximately half the number of scans. The gimbal pitch travel will then allow for two spot images of the same area from different aspect angles.

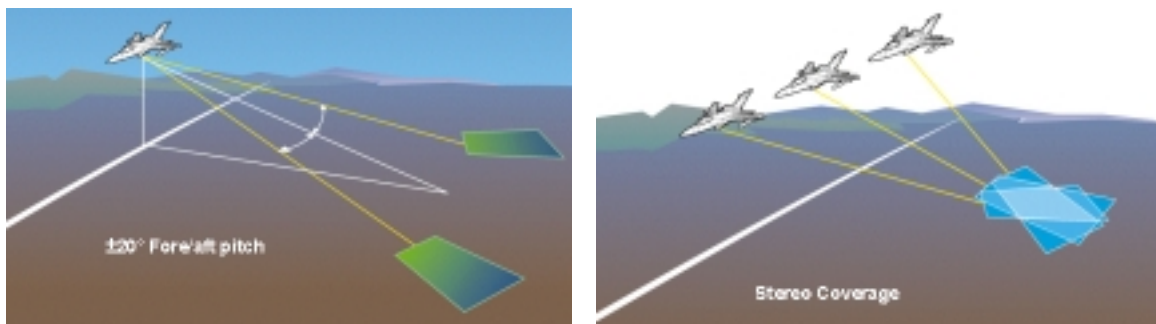


Figure 6. DB-110 provides up to 20° pitch angle to image fore/aft and to collect stereo imagery.

4. MULTI-MISSION OPERATION

The capabilities provided by the DB-110 differ significantly from past sensors. To put this in context, Table 2 was created to delineate standard recce capabilities. The categories include:

- Usage: Day/night
- Sensor: Short-range or long-range (standoff)
- Altitude: Low/medium/high
- Platforms: Penetrating, standoff, UAV

Table 2. Recce Capability Matrix

	Day				Night			
	Short Range		Standoff		Short Range		Standoff	
	Low	Medium Level	High		Low	Medium Level	High	
Penetrating								
Standoff Platform								
UAV								

This capability matrix can be utilized to evaluate which roles a given sensor/platform can perform. Similarly, mission planners can utilize it to evaluate gaps or redundancy in capabilities among in-service systems. A single, long-focal length dual-band LOROP utilized on a high altitude standoff (only) platform would fulfill roles as shown in Table 3.

Table 3. Capability of Dual-Band LOROP

	Day				Night			
	Short Range		Standoff		Short Range		Standoff	
	Low	Medium Level	High		Low	Medium Level	High	
Penetrating								
Standoff Platform								
UAV								

Using the DB-110 on a tactical aircraft (e.g. F-16, Tornado) that can perform both a penetrating mission and standoff fills in many more capabilities than a single focal length LOROP sensor. As shown below in Table 4, both medium and high level operations can be accomplished at day and night.

Table 4. Capability Dual-Band LOROP using Long-Range and Short-Range Optics

	Day				Night			
	Short Range		Standoff		Short Range		Standoff	
	Low	Medium Level	High		Low	Medium Level	High	
Penetrating								
Standoff Platform								
UAV								

The options of using either a long-range or short-range system gives the mission planner the flexibility to collect close range, overflight imagery or long-range standoff targets (Figure 7). With the short-range system, the DB-110 sensor can operate effectively at slant ranges down to less than one nautical mile. Thus in operations, the aircrew has the flexibility to alter the mission plan by flying under the weather to achieve target coverage.

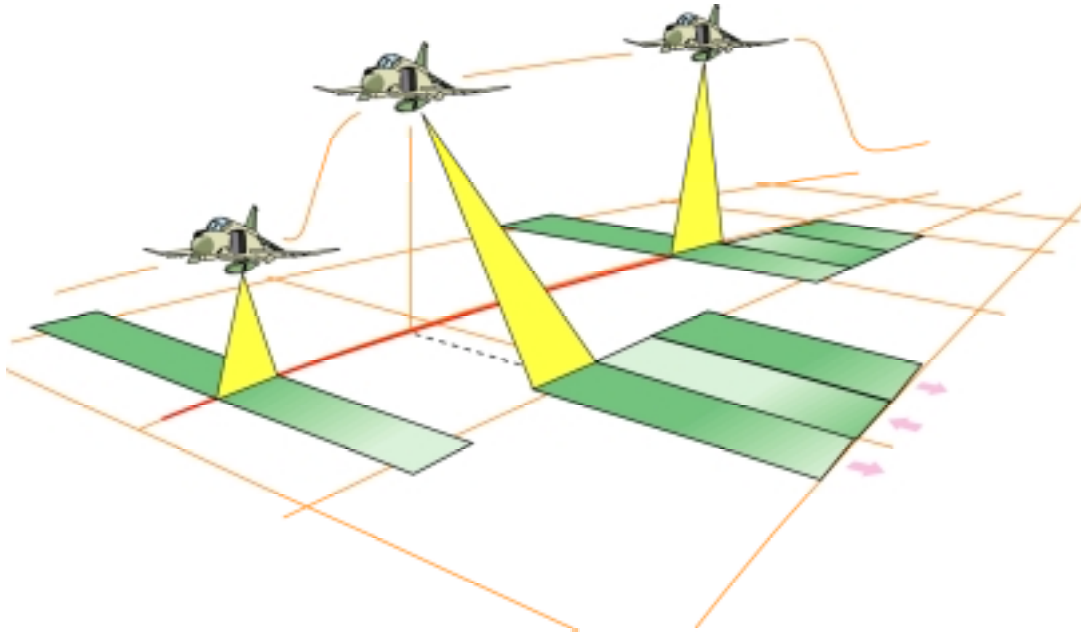


Figure 7. Multi-mission flexibility provided by short-range and long-range optics.

5. DB-110 FLIGHT DEMONSTRATIONS

In addition to building the DB-110 sensor, Raytheon built a pod suitable for carriage on a Tornado aircraft and demonstrated the DB-110 in England in January-February 1997. The pod contained the DB-110 sensor, recce management system, Ampex tape recorder and power supply. The pod was fitted with two side-viewing windows.

Figures 8 and 9 illustrate daytime visible and nighttime infrared scans collected in 1997. All imagery was collected from the Tornado flying at approximately 24,000 feet and 0.9 Mach. Both images represent the performance of the long-range imaging system.

In the daytime scene, small villages and roads are distinguishable even in the overview image (left hand side), which allows the analyst to narrow his/her search for the targets of interest. Two areas of interest are shown at full resolution on the right. At this range larger objects are still easily identified, for example the lattice structure on the high tension tower and trucks on the highway. The infrared image is presented in a similar manner with the full scan show at the left, and an enlargement to the right. Activity in the city center can be detected even at relatively long range.

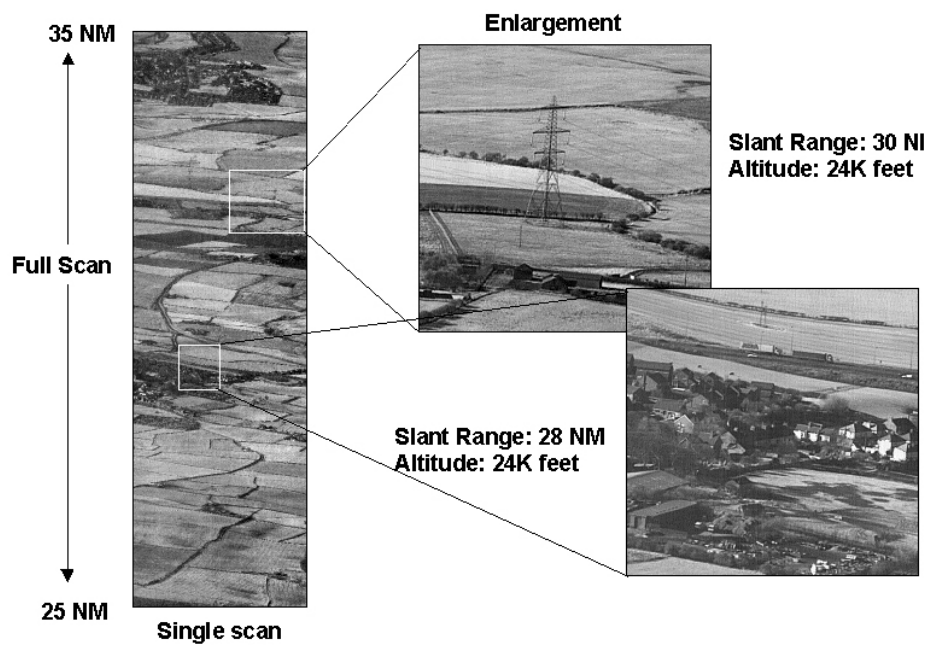


Figure 8. DB-110 Daytime visible image scan from 1997 demonstration.
Unclassified Crown Copyright

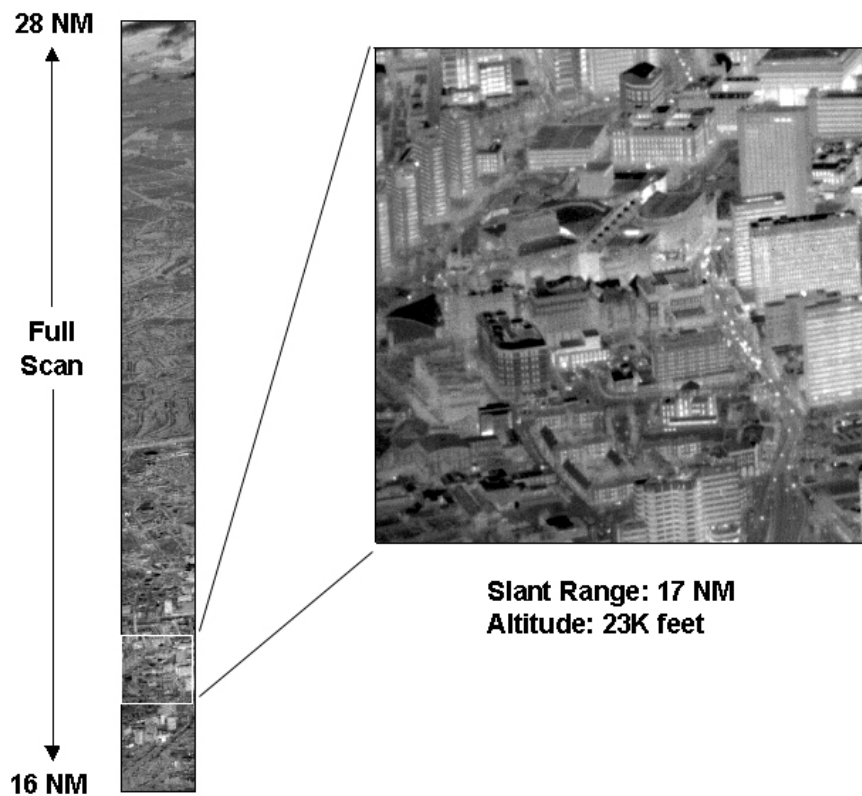


Figure 9. Nighttime infrared scan from 1997 demonstration.
Unclassified Crown Copyright

Raytheon conducted the UK flight demonstration as part of their strategy for the UK RAPTOR program. RAPTOR, Reconnaissance Airborne Pod for Tornado, was a competition conducted by the UK MOD. The need for a medium level imaging capability for the Tornado became evident during the Gulf War and subsequent operations over Bosnia and Iraq. Raytheon was selected for RAPTOR and will supply a total of eight airborne systems and two data link ground stations.

After the RAPTOR award, the Royal Air Force used the Raytheon DB-110 pod in 1998 to conduct additional flight trials (Figure 10). Over thirty flights were made, the objectives of which were to broaden the RAF's experience of EO/IR LOROP operations to "risk-reduce" the main procurement program, support operator training, and CONOPS development. Similar to the first flight trial, the flights included both day and nighttime collections and at a variety of altitudes. Imagery examples are presented below.



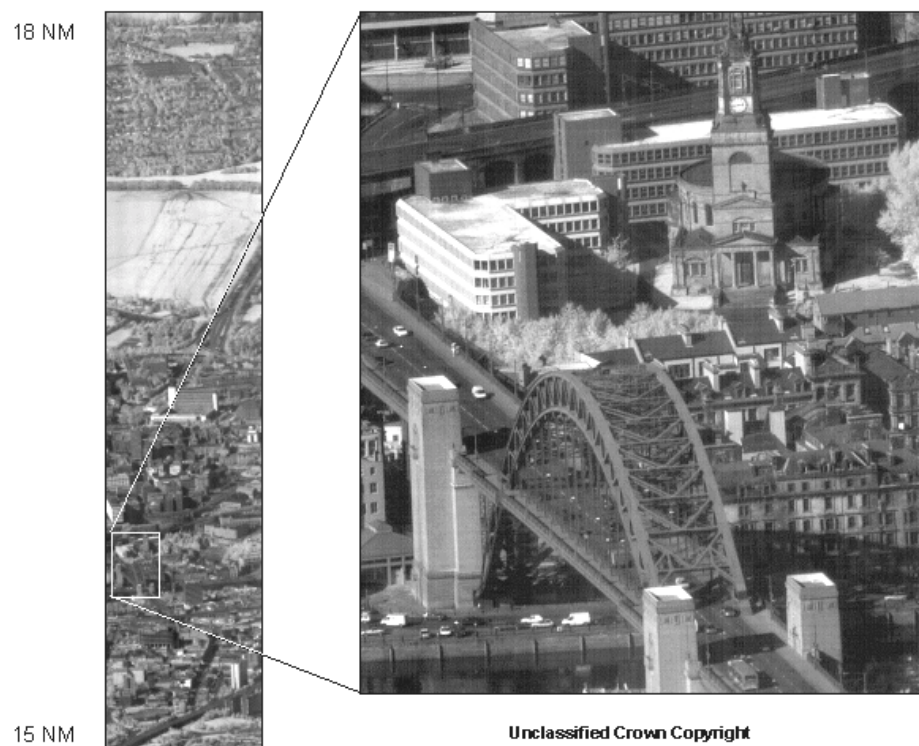
Figure 10. RAF tornado aircraft used to conduct 1998 DB-110 flights.
Unclassified Crown Copyright

Figure 11 shows a daytime visible wavelength image. The full scan is shown on the left, ranging in off-track range from 11 – 12 nm (near to far edge of scan). A full resolution enlargement of a region of interest is shown on the right. Vehicles are easily identified and people easily seen at this range. Figure 12 is collected at a further range, 16 nautical miles. In the enlarged image, people can still be recognized.



Unclassified Crown Copyright

Figure 11. Daytime visible image collected at 11 nautical miles.



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Figure 12. Daytime visible image collected at 16 nautical miles.

Both daytime and nighttime MWIR imagery provide additional information to the imagery analyst. In the daytime, MWIR imagery appears very much like visible due to the high degree of reflected solar energy that is present in that waveband. This is illustrated in Figure 13.



Figure 13. Daytime infrared image.
Unclassified Crown Copyright

Figure 14 is illustrative of nighttime IR imagery. Nighttime IR imagery has a unique appearance, as it is purely a result of emitted thermal energy in the scene. It is possible to “see” the level of fuel in the POL storage tanks based on their residual thermal signature. The dense fuel oil, which would be heated during the daytime, retains some of that heat throughout the night. The sides of the tank cool more quickly at night than the fuel, and are lighter in appearance in the thermal IR image. The tops of the tanks appear black as they are reflecting the “cold” sky.



Figure 14. Nighttime MWIR image illustrating thermal signatures of fuel storage tanks.
Unclassified Crown Copyright.

With digital imagery, the IA can alter the grayscale presentation on a workstation display to optimize his/her exploitation task. Figure 15 shows two renditions of the same nighttime MWIR image. On the left, a standard MWIR “white hot” polarity presentation is shown in which hotter objects are mapped to (presented as) white and cooler to black. In general, this facilitates quick recognition of thermally active objects, such as the fuel line. The opposite polarity is shown on the right (“black hot”). Thermally inactive objects, such as buildings and other structures, take on a more “natural” appearance as if illuminated by skylight. This presentation is similar to a reflected energy image (such as daytime visible wavelength) and may be preferred for exploitation of the general area.



Figure 15. IR imagery can be presented as white hot (left) or black hot (right) to facilitate exploitation of thermally active or inactive objects.
Unclassified Crown Copyright

Digital LOROP images can be combined with other data types for exploitation or mission planning assistance. Figure 16 illustrates the process of correlating two images. The upper two images are MWIR image and a map of that same area that has been registered to the IR image. In the bottom lower image, the map and image have been combined. The image blends from 100% map on the left-hand side to 100% image on the right.



**Figure 16. Example of image correlation between nighttime MWIR image and map.
Unclassified Crown Copyright.**

The Raytheon DB-110 was also flown in Australia during 1999. Objectives were to support analysis of day and night reconnaissance imagery under severe weather conditions imposed over both land and littoral environments. In addition to the challenges imposed by the atmospherics, the DB-110 Tornado pod was carried on an outer wing station of a Royal Australian Air Force F-111 aircraft (Figure 17).

Typical reconnaissance installations utilize the centerline station to minimize the effect of the platform disturbances. Due to the size of the Tornado pod, it was necessary to fly on the outboard station and accept the higher levels of aircraft motion. In spite of the environment, the DB-110's vibration isolation system successfully mitigated the effects of the platform dynamics and returned imagery within budget.



Figure 17. DB-110 Tornado pod fitted to outboard wing station of F-111.

Additional flight tests are under consideration for the DB-110 in 2000. To date, the Raytheon DB-110 remains the only LOROP system to have demonstrated performance from tactical platforms by day and night.